Circular No. 6089
November, 1928.

INFORMATION CIRCULAR

DEPARTMENT OF COMMERCE - BUREAU OF MINES

PHYSIOLOGICAL FACTORS OF MINE VENTILATION [1]

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INTRODUCTION

Ventilation is one of the most vital factors in the health, safety, and efficiency of the miner. Some investigators consider that probably the only really effective means of preventing silicosis is by use of a system of ventilation which admits large quantities of fresh clean air to the face and dilutes and forces the dusty air out as soon as formed. Such a system of ventilation would also lessen or remove the hazards from any toxic gases that might be present in the mine air. In hot deep mines the cooling of this fresh clean air would prevent deleterious effects on the health and eliminate the inefficiency incident to working in excessive heat; and there would be a reduction in accidents as a result of the decreased fatigue and improved health of the miners.

SUMMARY OF RECENT INVESTIGATIONS ON SILICOSIS

According to Mavrogordato[3] there are two important factors in the disabling type of miners' phthisis: (a) The phthisis-producing dust; and (b) the tubercle bacillus. He considers that no worthwhile improvement in the incidence of silicosis can be obtained until dust concentration is reduced to 20 mg. per cubic meter, as phthisis-producing dust is not removed until this level is reached. At this level there is still a heavy incidence of a grave form of the disease which becomes very aggravated after nine years' service. There is great improvement in health when dust is reduced to 5 mg. per cubic meter; it is only at this level that phthisis-producing dust is removed to any appreciable extent. With 5 mg. per cubic meter of dust, a less grave form of disease is produced and the incidence is about one-half that of the form associated with

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1 - Report of the chairman of the Subcommittee on Physiological Factors, of the Committee on Ventilation of the American Institute of Mining Engineers, presented at the meeting in New York City on February 20, 1928. The Bureau of Mines will welcome reprinting of this article but requests that the following footnote acknowledgment be used: "Printed by permission of the Director, U. S. Bureau of Mines. (Not subject to copyright.)"

2 - Chief surgeon, U. S. Bureau of Mines; surgeon, U. S. Public Health Service.

3 - Mavrogordato, A., Contributions to the study of miners' phthisis. Published by the South African Institute for Medical Research, Johannesburg, December, 1926, 83 pp.

20 mg. per cubic meter. As long as the amount of dust inhaled was believed to be the only factor in determining disablement and death from silicosis, it was thought that dust concentration had only to be reduced to a level at which a harmful amount could not be inhaled within an ordinary working life. This level, 5 mg., was reached between 1911 and 1916, and was associated with a genuine reduction in phthisis-producing dust as opposed to total dust. For about six or seven years dust concentration in the mines has been below the 5mg. level and at approximately the 2mg. level (300 to 350 c.c. light-ground, or 800 to 900 dark-ground konimeter counts), yet this level is still associated with silicosis production. There have been about 40 cases of the disease; 37 of the men affected were exposed for part of their time to conditions obtaining prior to 1916, and three have passed the initial examination since.

In addition to the two factors mentioned above - dust and tubercle bacillus - Mavrogordato suggests a third factor, water droplets. He is of the opinion that if the concentration of air-borne dust can be held without the use of water at the level at present obtained by the use of water, miners' phthisis as far as the Witwatersrand is concerned possibly can be eliminated and, incidentally, the temperature problems solved. Some work has been done toward this end, and the matter is considered worthy of further investigation.

Mavrogordato brings up the question as to whether it may not be possible to assist resistance by the use of an antituberculosis vaccine and suggests that it be tried out among the 80,000 native miners on the Witwatersrand. He says also that there is need of further means of assaying the resistance to tuberculosis of apparently healthy men who wish to enter a phthisis-producing industry; that is, some method is desired for determining whether an apparently healthy worker is gaining, maintaining, or losing resistance to tuberculosis.

According to Watkins-Pitchford[4], the measures that have been taken in South Africa to prevent the occurrence of silicosis and tuberculosis have resulted as follows: In the whole body of working miners the attack rate for simple tuberculosis has been reduced from 259 per 100,000 in 1917-18 to 90 in 1923-24, while the incidence rate for tuberculosis with silicosis has fallen in the same period from 860 to 164. Among the native laborers the incidence rate for simple tuberculosis has fallen from 576 in 1916-17 to 328 in 1923-24. The production of cases of simple silicosis in the "anteprimary stage" was first recorded in the year 1920-21, as this state was not legally recognized until August, 1919. In the former year, in addition to the anteprimary stage cases, the disease declared itself immediately in the "primary stage" in 17 cases; while during the year 1923-24 only one case originated in the primary stage. No case has originated directly in the "secondary stage" since the year 1918-19. That the disease is assuming a less severe type is indicated by the fact that the proportion surviving out of each year's new cases of simple silicosis is increasing year by year; for example, after the lapse of four complete years 76.4 per cent of the

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4 - Watkins-Pitchford, W., "The silicosis of the South African gold mines, and the changes produced in it by legislative and administrative efforts": Jour. Ind. Hyg., vol. 9, No. 4, April, 1927, pp. 109-139.

1917-18 cases, 81 per cent of the 1918-19 cases, 84.4 per cent of the 1919-20 cases, and 88.5 per cent of the 1920-21 cases were alive. The use of the X ray is important in diagnosis, as over 40 per cent of persons compensated without radiography were later found free from silicosis. As to future progress, Watkins-Pitchford says that any further and markedly effective progress is contingent upon a full and wide recognition of the communicability of tuberculosis, and of the necessity for taking active measures to protect the mine worker from infection.

According to Collis[5] the most recent official mortality statistics available for England and Wales, especially prepared to bring out occupational risks, provide definite evidence that groups of workers exposed to a silica-dust risk experience high mortality from bronchitis, pneumonia, phthisis, and chronic nephritis. Mortality from phthisis in an occupation with a silica-dust risk always exhibits its highest incidence late in life. Silicotic tuberculosis appears to be less infectious than ordinary tuberculosis.

Laboratory experiments by Carleton[6] in which guinea pigs were exposed to hematite (Fe_2O_3) and levigated iron indicated that, as compared with flint, ground picher, feldspar, or china clay, the hematite dust is comparatively harmless, although it does not follow from these observations that hematite, if inhaled over long periods, might not promote a fibrosis upon which tuberculosis might become grafted. The histological reaction of the lung toward hematite is rather like that toward shale or coal-dust. A number of animals died in a group in which two-hour exposures to iron-dust were attempted. As there was no epidemic among the animals and the findings at necropsy did not bear out the hypothesis that death was due to mechanical blocking of the air passages, Carleton supposes some toxic effect. That toxic effects have not been noted among workers in the shops where iron castings are drilled is probably due to the fact that human beings are never exposed to the massive inhalations used in these experiments. The immediate effects produced by iron-dust in the lungs were proliferation and thickening of the alveolar epithelium and a varying degree of bronchitis. Phagocytosis was brisk. Under the conditions of these experiments, iron-dust was found to be more harmful than hematite. No permanent lesions were caused by the hematite, but the iron-dust produced greater inflammatory changes and some permanent alterations (e.g. a slight fibrosis) in the lung.

A clinic has been established at Timmons, Ontario, Canada, to determine the extent of tuberculosis and silicosis among the gold miners of the district, a number of whom have been examined. The work being done in the United States, England, and South Africa has been observed, and information as to methods used in these countries has been sought for application to the problems in Canada.

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5 - Collis, Edgar L., "The statistical characteristics of dust phthisis (pulmonary silicosis)": Jour. Ind. Hyg., vol. 26, No. 2, London, July, 1927, pp. 227-234.

6 - Carleton, H. M., "The effects produced by the inhalation of haematite and iron dusts in guinea pigs": Jour. Hyg., vol. 26, No. 2, London, July, 1927, pp. 227-234.

Specialists have been invited to inspect conditions and make suggestions. Under a ruling by the Workmen's Compensation Board, compensation for disablement due to silicosis will not be paid while the employee continues at work where he is exposed to silica dust, and if he at any time resumes such work, no additional award will be given for further disablement.

At Broken Hill, Australia, periodic examination of miners is required, and since 1921 all tuberculous and silicotic workers have been excluded from the mines, both on the surface and in underground workings. Employment is provided elsewhere for the silicotic, and compensation is given to the tuberculous and to the disabled silicotics.

A clinic for examination of miners has been in operation for several years at Bendigo, Australia, under the direction of the Commonwealth Department of Health. A similar clinic has recently been established at Kalgoorlie. A large sanitarium, supported by the State of Western Australia, has been operating for a number of years; a majority of the patients are tuberculous or tuberculo-silicotic miners from the Kalgoorlie district.

Because of the favorable effect of the inhalation of certain dusts in industry, animal experiments were tried out in Germany[7] to determine the effect of the inhalation of coal-dust, free from irritating particles, upon tuberculosis The experiments investigated the effect of inhalation of coal-dust upon previous tuberculous infection, as well as the effect on the healthy lung and on tuberculosis in animals that had inhaled coal-dust over a long period. Even though the coal-dust particles were found in the alveolar epithelium and interstitial tissues, and in some cases had already entered the subtracheal lymph nodes, there was found no increased connective-tissue formation and no change in the form of resulting tuberculosis.

During the past year a cooperative agreement was entered into between the United States Bureau of Mines, the Metropolitan Life Insurance Co., and the Tri-State Zinc and Lead Ore Producers Association (composed of mine operators of the three States of Kansas, Oklahoma, and Missouri) to expand the clinic which has been in operation for a number of years by the Bureau of Mines at Picher, Okla. It is proposed to afford facilities for examining each workman in the district at least once a year to determine the effects, if any, of working conditions on the health of the miner. A building adequate for the work has been constructed and equipped and is now in use. During the operation of the clinic at Picher about 10,000 miners have been examined. At the present time five doctors, an X-ray technician, and several clerks are employed, and about a thousand examinations are being made each month.

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[7] - Henius, K., and Richert, O., "Zur Frage der Einwirkung von Kohlenstaubinhalation auf die Bindegewebsentwicklung in der Lunge. Experimentelle Untersuchungen am Kaninchen. I. Die Einwirkung der Kohleninhalation auf die Lunge des Kaninchen bei vorhergehender tuberkulöser Infektion": Ztschr. f. Tuberk., Jahrg. 46, 1926, p. 123. Quoted from Am. Rev. Tuberculosis, vol. 17, XVII, No. 2, February, 1928. p. 44.

The use in coal mines of inert dusts for the prevention of coal-dust explosions may introduce a health hazard in the form of silicosis unless care is taken to exclude the types of dusts that are conducive to this hazard. Attention has been given by the Bureau of Mines to various means for making rapid tests of the suitability or unsuitability of a dust. While chemical and microscopic examinations are made and tentative specifications formulated, all the factors involved in producing silicosis are not well understood at present and no direct interpretation of chemical composition and physical properties can be made. In this connection, intraperitoneal injections of finely ground dusts have been made in guinea pigs and after a period of time the results have been correlated with those obtained by exposing animals to dusty atmospheres. While fibrous tissue forms too slowly for the inhalation method to be practicable for a specification test, the results thus far are in agreement with the intraperitoneal injections; this indicates that the injections may possess value as a rapid test. A large number of different materials have been tested by injection, but more must be so examined before the true value of the test can be ascertained.

SUMMARY OF RECENT INVESTIGATIONS ON HIGH TEMPERATURES

Air-conditioning underground is of continually increasing importance for the progress of mining at great depths in South Africa. According to the annual report of the Secretary of Mines of South Africa[8], on the Witwatersrand the mine having the highest death rate from accidents during 1925 was the Village Deep with an accident rate of 4.35 per 1,000. The report states that the high temperature in this mine is no doubt having an indirect effect in causing accidents. A special investigation was made by Mavrogordato and Pirow[9], owing to four cases of sudden death that occurred between September 29, 1925, and January 1, 1926, in the Village Deep mine. Since August 20, 1926, managers have been required to report cases of heat apoplexy just as they do serious accidents. The most striking result of the inquiry was the demonstration of the importance of acclimatization as a safeguard. It was found that of the 18 fatalities at the Village Deep and other mines, of which particulars have been obtained, 13 occurred to natives who were on their first or second shift underground, and the other cases were of natives who were on their first or second shift after removal to a hot working place or upon return to work after coming out of the hospital.

At the Village Deep gold mine, and later at the City Deep gold mine, a system of probationary gangs was established for such acclimatization. These gangs do no "lashing" or tramming, and special boss boys for the gangs are given instructions to see that the natives in them do not exert themselves too much. Endeavors are being made to increase and improve ventilation and air movement by air coursing and boosters, and the managers of the Village Deep have been experimenting on a small scale with the use of ice for cooling the air in development ends. Blocks of ice were sent down to the lowest levels, but it was found that merely placing blocks in various parts of the workings reduced the temperature only to a small degree. Better results have been obtained with the use of ice in ventilation pipes.[10] During the day shift, after about three hours' use of ice and with the machines running, the temperature in the vicinity of the face is reduced about 7° F. dry bulb, a cool zone being created that extends to about 20 feet back from the face, which is 3 to 4° F. cooler than the main ventilating current at the last holing, and actually feeds the dead-end. At midday it is possible to maintain at the face a temperature of between 11 and 12° F. less than the virgin rock. The usual procedure is to have a 100 cwt. block of ice in the pipe at one time, by which means the temperature of about 1,500 cubic feet of air per minute is reduced by 6° F. dry bulb.

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[8] - Union of South Africa, Department of Mines and Industry, Annual Reports of the Secretary for Mines and Industries and the Government Mining Engineer for the calendar year ending 31st December, 1925; Pretoria, 1926, p. 51.

[9] - Mavrogordato, A., and Pirow, H., "Deep-level mining and high temperatures": Jour. South African Inst. Eng., vol. 25, No. 7, February, 1927, pp. 101-125.

Experiments were carried out with varying quantities of ice, and with about 2½ cwt. of ice spread over the last 12 feet of pipe the temperature of the air delivered at the face was reduced from 89.4 to 73° F. dry bulb, or slightly more than 16° F. As a result of these experiments, it is considered that the use of air-cooling plant on the surface would be practically of no avail and that a central air-cooling plant, placed anywhere underground in the main intake, would give a very small measure of relief, if any, in the working places. It has also been pointed out that there may be danger from leakage of ammonia gas; but this might be obviated by the use of other refrigerants. The great difficulty is to get rid of the condenser heat without contaminating the incoming air. Nevertheless, it is thought that if satisfactory general cooling of mine air is to be accomplished, it will be by means of small portable units. The importance of concentrating air supply on the hottest levels of the mine by maximum fan capacity and perfect air control should be emphasized.

In addition to the precautions mentioned the following also are taken: Natives arriving at the mine and passed by the mine medical officer for underground work are divided into three classes: (1) No previous underground experience on the Witwatersrand; (2) previous underground experience on the Witwatersrand but not in the Village Deep; and (3) previous experience in the Village Deep. Natives of class 1 commence with 12 days in a probationary gang, and those of class 2 with 6 days. Natives discharged from hospital are kept on the surface for a shift, and then the native supervisor decides whether to keep the natives on the surface or to place them in a probationary gang for 6 days, 12 days, or more than 12 days. The bigger and stronger natives are selected for tramming and lashing work. Drinking-water tanks are provided at all stoping levels and filled with water containing a little lime juice and seven grams of ordinary salt per gallon. Natives are provided with gallon tins which they fill at the beginning of the shift. Lashing, tramming, and machine boys are given a meal of bread and meat at about 10 to 11 a.m. daily while at work. The food is sent underground at 9 a.m. in special tins made up according to the size of the gang.

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[10] - Tillard, M. O., and Ranson, E. C., "Deep-level mining problems": Queensland Gov. Min. Jour., August, 1926.

The four recognized methods of cooling hot working places on the Witwatersrand are (1) general movement of air; (2) general cooling of air; (3) local movement of air; (4) local cooling of air.

The local air movement on the jet or douche principle appears to be the most helpful method, and in very hot places, above 86° F. wet bulb, it might be reinforced by cold sprays. If enough air were available the same result would be obtained by giving each man a compressed air jet to himself for cooling purposes.

A number of deaths from heat apoplexy also occurred in the lower levels of the East Rand Proprietary Mines during 1926. This would indicate that conditions are becoming serious in that district also.

The best-known system of mine refrigeration on a large scale is at the Morro Velho of the St. John del Rey Co., Ltd.[11] The outside air, at a temperature of about 80° F., with a moisture content of about 120 grains of water per pound of dry air, is cooled by refrigeration to a little above 40° F., which at the same time reduces the moisture content to a little over 40 grains of water per pound of dry air. This cooled and dried air is circulated throughout the working places by fans, one on the surface and one at the top of the upcast on the 4,126 level. However, in passing down through the mine workings to the working faces, the air current takes up so much heat and moisture from the surfaces with which it comes in contact that by the time the working face is reached the air has a dry-bulb temperature of 98° F., or essentially the same temperature as if it had not been cooled at the surface. The moisture content, however, is not so great, as it is only about two-thirds that of the ventilating current at the working face when the air has not been cooled and refrigerated. The net result is that the cooling power of the ventilating current, as determined by the wet katathermometer, is increased from 7.7 up to 20.5 millicalories per square centimeter per second. Of this improvement in the cooling power 80 per cent is due to the lowering of the temperature of the air and 20 per cent to the increased velocity caused by the second fan. The original condition, which gave a cooling power of 7.7 millicalories per square centimeter per second, was a temperature of 101.5° F. dry bulb, 87° F. wet bulb, and a computed air velocity of 220 feet per minute, which corresponds to an effective temperature of 88° F. The condition after refrigeration, and after the second fan was installed, was 97.4° F. dry bulb, and 76.2° F. wet bulb, and an air velocity of 540 feet per minute, corresponding to an effective temperature of 78.7° F. During the 16 months preceding the installation of the cooling plant in the Morro Velho mine there were 20 fatal accidents, while during the 16 months' period following the installation there were only 6 fatal accidents.

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11 - Engineering and Mining Journal, Refrigeration of mine air: vol. 123, No. 1, January 1, 1927, p. 22.

In the Zeche Radbod (Germany)[12], coal is mined at depths of between 2,600 and 3,250 feet, and rock temperatures up to 111° F. are encountered. If the temperature in a working place rises above 82.5° F., a miner can not be compelled to work a full six-hour shift and works what is known as a short shift of five hours instead. In the summer of 1920 the number of short shifts had risen to 60 per cent of the total number of shifts and in June, 1921, to 83 per cent, so that it became imperative to reduce the temperatures in the working places. This was done by shortening and widening the main air passages and by the installation of extra fans on the surface. By this means the percentage of short shifts was reduced to zero in February, 1923, rising only to 25 per cent in the following summer, whereas in the winter of 1920-21 it had never been below 60 per cent.

A further increase of the ventilation was decided upon. To do this a fifth shaft was commenced; as the work would take some years, other means of cooling the mine were resorted to as a temporary measure. A system of water sprays was installed at the collar of the only downcast, and in addition a sort of radiator was installed in a main crosscut at a depth of 3,150 feet. This "radiator" consisted of a large number of 2-inch, 3-inch, and 5-inch pipes, arranged horizontally over a length of 340 feet with a total surface of 19,000 square feet. The water circulated through the system was taken from the town supply and conducted down from the surface in an insulated column. The results were disappointing, as the average reduction in temperature was under 1° F. and the maximum was 1.8° F. An attempt was then made to cool the water before sending it underground. A second-hand ammonia freezing plant was bought and installed near the collar of the downcast. This plant was insufficient for both the sprays and the underground "radiator" and was used solely to cool the water that fed the latter. This cooling of the mine air did not entirely eliminate the number of short shifts, but the cost of running the plant was more than offset by the increased production. As it is expected to mine to a greater depth and to reach rock temperatures up to 136° F., the manager of the Zeche Radbod has expressed the opinion that some means of artificially cooling the air will become imperative

In England a refrigerating machine was tried out underground in the Pendleton colliery by the committee on the control of atmospheric conditions in hot and deep mines.[13] The results were not satisfactory, as the machine either was too small or was erected too far from the coal face. The difficulty of maintaining a large engine house near the coal face is obvious; the ideal arrangement would be to install near or at the coal face a machine of smaller construction but of the same capacity. The makers of the machine asserted that such an installation is possible and are about to construct a machine more in conformity with mining requirements. Choice of the special refrigerant is, however, very limited, inasmuch as for mining purposes it is almost essential that any vapor liberated normally or by accident should be odorless, nonpoisonous, nonexplosive, and noninflammable.

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[12] - Flugge--Desmidt, R. H., "Discussion of rock and air temperatures in deep level mines": Jour. Chem. Met. and Min. Soc. of South Africa, February, 1926.

[13] - Hancock, W., "Local air-conditioning underground by means of refrigeration": Colliery Guardian, vol. 133, No. 3449, February 4, 1927, pp. 266-268.

A special investigation was conducted in the Pendleton colliery by the Industrial Fatigue Research Board[14] as to the actual difference in the working capacity prevailing under existing conditions in hotter and cooler seams, respectively, in coal mines. In this investigation abundant evidence was obtained to show that physiologically unfavorable atmospheric conditions may often have a detrimental influence on working capacity, particularly where occupations involve heavy muscular effort.

The index of working capacity usually adopted - namely, output - could not be applied at the Pendleton colliery, owing to the large variation in the ease of getting coal; therefore, the duration of the rest pauses taken while at work and the time required to carry out a given task were taken as an approximate measure of the working capacity. In addition, some information was obtained on the relation of atmospheric conditions to accident incidence. The report shows that there is a heavy loss of working time, due to resting, in the hot seams as compared with the cool; although the present investigation, being based on actual observation of the colliers concerned, was necessarily limited in scope, and dealt, in fact, with the different seams in only two collieries, the consistency with which working capacity is shown to be smaller in the hotter seams suggests that the same effect would hold generally throughout the coal industry. These rest pauses are taken almost unconsciously, and under existing conditions are probably actually necessary in the interests of the worker.

Economically rest pauses are a source of loss of production; if the time consumed in rest pauses by the total number of men working in hot seams could be ascertained, this source of loss would probably be found to be an important one. The same conclusion is indicated by the comparison of the tub-filling times and the accident rates. Under the most unfavorable atmospheric conditions, the working capacity of the men was only 59 per cent as great as under the most favorable conditions. The working capacity fell off at a more and more rapid rate as the wet kata cooling power diminished; the decrease was especially rapid when the cooling power dropped from 9 to 6.4. Only six men were observed under the worst conditions, and their involuntary rests from work were much greater than those of the other groups. In the next two groups, at wet kata cooling powers of 9 and 10.8, the number of men observed was 42 and 47, respectively, so that these results are more reliable. Arguing from the loss of working capacity then observed, it seems probable that the loss, under the worst conditions, would be 35 per cent. The rest pauses taken did not begin to increase until the wet kata cooling power dropped below 14.6.

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[14] - Vernon, H. M., and Bedford, T., "The relation of atmospheric conditions to the working capacity and the accident rate of coal miners": Colliery Guardian, vol. 133, No. 2338, January 28, 1927, pp. 195-197.

To test the effect of air movement on working capacity, 53 observations were made in which the wet-bulb temperature ranged from 74 to 76°. When the air velocity increased from 13 feet per minute to 21 feet the rest pauses taken fell from 12.7 minutes per hour to 9.5 minutes. With greater air velocities there was no further fall in the total rests taken, but the voluntary rests fell a good deal. The involuntary rests are comparatively unimportant, so the effective rests were considerably shorter at the highest air velocities. The results obtained suggest strongly that in many industrial processes the judicious introduction of short pauses is not only much appreciated by the workers, but may also be followed by an increase in output of the order of 5 or 10 per cent, in spite of the diminution of working time.

The data obtained support the theory that atmospheric conditions influence the accident rate; but it is evident that, in order to get a really satisfactory proof, it will be necessary to obtain not only a much larger body of information, but information relating to a wider range of atmospheric conditions.

In connection with the subject of fatigue it is interesting to note that experiments made by Radoceanu[15] prove the results obtained by Weichardt in 1905-07 indicating that during muscular exercise a toxin is formed in the muscles which can be easily separated from the other extractives by dialysis. He found that this toxin, if injected into fresh animals, causes intense fatigue, fall of temperature, stupor, and death. It has the properties of a true toxin. It is not dialyzable. The toxin is saturated by the antitoxin both in the living body and in the test tube according to the law of multiples. Unlike the toxin, the antitoxin is readily dialyzable and may be preserved for a long time. If taken internally, the antitoxin seems to have a remarkably stimulating action on the muscles.

Much field and laboratory work has been done by the United States Bureau of Mines on the effects of high temperatures and humidities. In the field, tests have been made at the request of the railway companies involved, to determine the ventilation necessary to dilute and remove the noxious gases produced by combustion of coal in the engines and to reduce the high temperatures in the engine cabs. Such tests were made in the Aspen and Wahsatch Tunnels of the Union Pacific Railroad, the Moffatt Tunnel in Colorado, and a number of tunnels located in Virginia, on the Chesapeake and Ohio Railway. In one test[16] the temperature in the cab of a freight engine was found to be high enough to cause a surface burn, but when the engine was worked under a lighter throttle no marked discomfort was experienced; this test indicates the relation of train manipulation to tunnel conditions.

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[15] - Journal American Medical Association. "Toxin of fatigue, Report from correspondent at Bucharest, November 29, 1927": vol. 90, No. 3, January 21, 1928, p. 219.

[16] - Sayers, R. R., Berger, L. B., and Yant, W. P., "Tests of Atmospheres in Chesapeake and Ohio Railroad Tunnels Between Clifton Forge, Va., and Hinton, W. Va.": Repts. of Investigations, Bureau of Mines, Serial 2858, February, 1928.

In the laboratory, studies are being made to determine the relative importance and correct correlation of the many factors influencing heat production and heat loss in man in order to have a definite basis for the direction of intelligent effort toward preventing deleterious effects. Some of the results of these studies may be summarized[17] as follows:

The effects on the human body of abnormal air temperatures are modified by humidity, air motion, exercise, physical condition of persons exposed, food eaten, clothing worn, and individual idiosyncrasy. Humidity increases the discomfort and ill effects of both high and low temperature. Comfort, as determined by both sense and physiological reactions, depends solely upon effective temperature. At 32° the effective-temperature line coincides with the dry-bulb temperature line; hence, in this particular case, dry-bulb temperature is the only factor in determining comfort. In the comfort zone, comfort depends equally upon wet-bulb and dry-bulb temperatures. At about 132° the effective temperature coincides with the wet-bulb temperature, and for this case the wet-bulb temperature is the only comfort factor. Below 32° the effect of humidity is reversed; that is, the lower the humidity the greater the feeling of warmth. The limiting physiological reaction caused by high temperatures, as determined by comfort, is not body temperature but the pulse rate. When this is above 135 the first symptoms of discomfort arise; when above 160 the effects are severe to distressing.

Air movement decreases the discomfort of high temperatures below 98° F.; moving saturated air above 98° F. is of no benefit and apparently is even disadvantageous. The upper limit in atmospheric conditions at which work can be performed efficiently corresponds to a dry-bulb temperature of 100° and a relative humidity of 30 per cent, or of 90 or 95° F. in still saturated air, even when stripped to the waist. The optimum temperature at rest is around 66° F.; and with hard work the optimum temperature is 59.5°; 43° F. is considered to be too cold with or without air movement, regardless of humidity. In still air no temperature is low enough to prevent outdoor work.

Normal clothing at ordinary humidity halves the cooling effect of wind, as compared with that obtained with the subject stripped to the waist. On the other hand, clothing under certain conditions is advantageous in increasing loss of heat by evaporation and decreasing heat gain by radiation and convection; in fact, man is capable of increasing evaporation materially by suitable clothing. At rest in still air with a temperature of 65 to 70° and with 100 per cent relative humidity, subjects stripped to the waist feel from "slightly cool" to "comfortable"; under these same conditions with moderately hard work, they feel "comfortable." At rest in still air with temperatures from 55 to 60° and 100 per cent relative humidity, clothing is required for comfort, while at moderately hard work under these conditions the subjects are "comfortable" to "cool" when stripped to the waist, and at 45 to 50° subjects working moderately hard feel "cool" when stripped to the waist.

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17 - Sayers, R. R., and Davenport, Sara J., "Review of Literature on the Physiological Effects of Abnormal Temperatures and Humidities": Reprint 1150, Pub. Health Repts., April 8, 1927, 63 pp.

During the past year additional work has been done on the making of effective temperature charts, and on the determination of thermal exchanges between the human body and the atmosphere and their relation to temperature and humidity.

In considering the use of refrigerants for air conditioning in hot mines and in industrial and domestic refrigeration, the toxicity of alkyl halides employed for this purpose is of importance due to the possible occurrence of leaks. The relative toxicity of methyl chloride, methyl bromide, ethyl chloride, and ethyl bromide, using guinea pigs as subjects, has been determined cooperatively by the U. S. Bureau of Mines with the National Research Council and the Dow Chemical Co. The order of increasing toxicity of the four compounds is ethyl chloride, ethyl bromide, methyl chloride, and methyl bromide.

SUMMARY OF RECENT INVESTIGATIONS ON SOME TOXIC GASES FOUND IN MINES

Oxygen.- In the mines oxygen is, of course, not toxic but necessary to maintain life, and the danger is usually that of oxygen deficiency rather than of excess. However, in connection with the use of self-contained oxygen breathing apparatus for rescue work and the administration of oxygen in the treatment of CO poisoning it is important to know the maximum exposure to high oxygen atmosphere that may be experienced day after day with no deleterious effects. Experimental work has been carried out by the U. S. Bureau of Mines in which it was found that 95 per cent oxygen may be inhaled for 16 hours a day for 50 consecutive days with no obvious ill effects to small animals, but that continuous exposure of 24 hours per day causes severe lung irritation and death in 3 to 4 days.

Methane or marsh gas.- Methane gas is important in coal mines and may be present occasionally in metal mines and tunnels. It has no physiological or noxious action but may dilute the oxygen of the air to such an extent as to produce the effects of oxygen deficiency. It also forms an explosive mixture with the oxygen of the air and may thus cause a disaster.

A device for detecting the presence of methane has recently been invented by Professor Martienssen, of the University of Kiel, Germany, and has been officially approved by the United States Bureau of Mines. This device fills the need of a reliable methane detector that is convenient to use and that will permit the keeping of all flames of every kind out of bituminous mines by doing away with the safety lamp. The characteristics that qualify the Martienssen detector for the task are simplicity, small weight and bulk, ruggedness, accuracy sufficient for the requirements, safety and dependability.[18] While the device is

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18 - Willhofft, F. O., "The Martienssen methane detector, a portable device for detecting the presence of methane in gassy mines, which is as easily used by a novice as by an expert": Min. and Met., vol. 9, No. 253, February, 1928, pp. 66-68.

not sufficiently accurate to enable the observer to read the percentage of gas on a scale and its accuracy is perhaps not greater than that of the flame lamp in the hands of an expert, it is much more accurate than the flame lamp in the hands of the average man or even in the hands of a good fire boss. It is accurate enough for practical needs and may be used by anyone after a single lesson.

Hydrogen sulphide.- A number of studies, particularly field studies in the petroleum industry, have been made by the Bureau of Mines[19] on the hazard from hydrogen sulphide. An investigation was made in the Texas Panhandle, Big Lake, and McCamey oil fields. Four deaths occurred from acute poisoning in one of these fields before the dangers of the gas were well known and before the depth of the poison gas zone was accurately determined. The concentration of hydrogen sulphide in the "sour" gas of this field ranges from approximately 0.2 to 0.6 per cent by volume. An exceedingly toxic atmosphere can occur in a mixture of this gas with air. If a gas contained only 0.2 per cent hydrogen sulphide, a mixture of equal parts of gas and air would be required to give a concentration of 0.1 per cent hydrogen sulphide; in such an atmosphere unconsciousness would result quickly from the hydrogen sulphide present.

Methods for the prevention of poisoning by hydrogen sulphide and methods of treatment have been outlined in the several publications by the bureau. While all the hazards have not been eliminated, a thorough knowledge of the properties and effects of hydrogen sulphide, with proper methods and equipment for working in contaminated atmospheres, will help to bring the total of accidents to the minimum.

Carbon monoxide.- Carbon monoxide is the most important toxic gas encountered in mines and is also the most frequent source of poisoning in industry as well as in the home. The increasing number of commercial garages calls for a better appreciation of the hazards involved and the development of methods to prevent accumulation of carbon monoxide in quantities detrimental to drivers and repairmen of cars. The Bureau of Industrial Hygiene of the New York State Department of Labor has started a comprehensive study of the carbon monoxide hazard in that State. In preliminary investigations of 31 public garages[20], 24 showed an excess of 0.1 per cent of carbon monoxide present. Of the 42 workers examined, 29 showed definite evidence of carbon monoxide in their blood and a number presented clinical symptoms of carbon monoxide poisoning.

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[19] - Sayers, R. R., Smith, N.A.C., Fieldner, A. C., and others, Investigation of Toxic Gases from Mexican and Other High-Sulphur Petroleums and Products: Bull. 231, Bureau of Mines, 1925, 108 pp.
Yant, W. P., and Fowler, H. C., Hydrogen Sulphide Poisoning in the Texas Panhandle, Big Lake, Texas, and McCamey, Texas, Oilfields: Bureau of Mines Repts. of Investigations, Serial 2776, October, 1926, 20 pp.
Fowler, H. C. Prevention of Hydrogen-Sulphide Poisoning in Handling and Refining High-Sulphur Petroleums: Bureau of Mines Repts. of Investigations, Serial 2847, December, 1927, 27 pp.

[20] - Mayers, May R., "The carbon monoxide hazard in industry": Ind. Hygiene Bull., New York State Department of Labor, vol. 3, No. 8, February, 1927, pp. 29-30.

The Bureau of Mines has made a number of investigations in Government garages and also in a large public corporation garage. In the Government Fuel Yards garage,[21] where continuous records of the carbon monoxide present were obtained through nearly three weeks in January, 1927, as high as 8.9 parts of carbon monoxide per 10,000 parts of air were obtained, but the average concentration throughout the working hours of a day in no case exceeded 1 part in 10,000. In the public corporation garage, where records were obtained from February to May, 1927, the highest average found through a working day was 1.64 parts per 10,000; the maximum was about 8.3 parts, but such high concentrations existed only momentarily. The highest average through any one hour was 4.33 parts per 10,000, which may cause headache in some persons. As no tests were conducted in the coldest winter weather when garages are more tightly closed to conserve heat and less ventilation takes place, it is possible that considerably more carbon monoxide than that reported accumulates in similar garages in the coldest weather. Tests were also made in several garages of the Post Office Department.

From examinations made in large garages, it has been found that most of the cases of carbon monoxide poisoning occur in the repair shop, because of the idling or running of the engines over a considerable period of time in a comparatively small space. This hazard can be overcome by the use of an exhaust system of ventilation connected with the muffler pipe of the automobile so as to draw all exhaust gases out of the building. Dangerous concentrations of carbon monoxide have not been found in the parking space in these garages, although occasionally concentrations occur that can produce symptoms.

An investigation by the Bureau of Mines has been in progress to determine the effect of repeated daily exposure of from 5 to 7 hours to low concentrations of carbon monoxide such as might prevail in tunnels, garages, and in certain mines. In this study a group of six men was exposed seven days a week and carefully observed for symptoms of poisoning, physiological changes, and psychological effects. The immediate occasion of this work was the opening to traffic of the Holland Tunnels in New York City, as it is especially important to have such information on carbon monoxide poisoning in order to determine the limits of safety for the traffic officers stationed in the tunnels and for passengers in automobiles in case traffic should be stalled for any length of time.

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[21] - Katz, S. H., and Frevert, H. W., "Carbon monoxide in two large garages": Jour. Ind. and Eng. Chem., 20, January, 1928, p 31.

The carbon monoxide recorder, designed by the Bureau of Mines for recording low concentrations of carbon monoxide in air has been adopted for use in the Holland Tunnels, and 14 recorders have been installed.[22] This instrument records on a time chart the carbon monoxide in parts per 10,000 and fractions thereof, and is sensitive to about 0.02 parts per 10,000 (2 parts per million). The range is from uncontaminated air to 9 parts of carbon monoxide per 10,000 parts of air. A warning bell is arranged to ring when the carbon monoxide reaches a concentration of 4 parts per 10,000 or more. This method of carbon monoxide analysis is the most accurate and sensitive yet devised for small concentrations of carbon monoxide in air. A sensitivity of 1 part per million is readily attained.

On the first day of the use of the Holland Tunnels, Sunday November 13, 1927, the traffic totaled 51,750 cars in 24 hours; at times it exceeded the estimated capacity of 1,900 cars per tunnel an hour, for a maximum of 2,371 cars passed through one tunnel in an hour and a maximum of 2,206 cars through the other. Although 33 per cent of the total fan capacity was held in reserve, the carbon monoxide as indicated on the recorders did not exceed 3.2 parts per 10,000 in either tunnel at any time, which is well under the maximum tolerable concentration of 4 parts per 10,000. The maximum average concentration for one hour in either tunnel was 2.2 per 10,000. On the second day of operation, a normal business day, the total traffic was only about a third that of the previous day. The carbon monoxide then showed a maximum concentration in either tunnel of 1.3 parts per 10,000 and a maximum average during any hour in any section of 0.7 parts per 10,000.

In connection with the carbon monoxide studies, experiments were conducted on men to determine the sense-affecting properties of certain chemicals, such as their intensity of odor and lacrimatory and irritant powers at various concentrations, with the object of finding some substance that might be added to manufactured gas to warn people, either awake or asleep, of the danger from escaping gas. A large list was compiled of substances that might be used for this purpose and a rather thorough survey was made of the literature on each. Then by a process of elimination those substances were selected for experimentation that apparently had no unsuitable properties. So far the results indicate that stenches are not of great value in awakening sleeping persons, either lacrimators or sternutators being more effective.

Some studies on present methods of treating carbon monoxide poisoning were carried out at Edgewood Arsenal. A comparison of the value of treatment by oxygen alone, by oxygen plus 5 per cent carbon dioxide, and by air plus 5 per cent carbon dioxide gave the following results:[23]

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22 - Katz, S. H., Reynolds, D. A., Frevert, H. W., and Bloomfield, J. J., A Carbon Monoxide Recorder and Alarm: Bureau of Mines, Tech, Paper 355, 1926, 34 pp.

23 - Walton, D. C., Eldridge, W. A., Allen, M. S., and Witherspoon, M. G., "Carbon monoxide poisoning": Archives of Internal Medicine, vol. 37, No. 3, March 15, 1926, pp. 398-407.

1. In dogs suffering from carbon monoxide asphyxia the difference in elimination time in animals treated with oxygen and those treated with oxygen plus 5 per cent carbon dioxide is slight, but both are much superior to the air plus 5 per cent carbon dioxide treatment.

2. Since the rate of elimination under pure oxygen is almost as rapid as with the oxygen plus 5 per cent carbon dioxide and since the oxygen treatment is more readily available, it is recommended that its use be continued, particularly in localities where transportation is difficult.

3. The air plus 5 per cent carbon dioxide treatment should be of value for rescue parties sent to inaccessible mines and especially in military operations.

In a short summary of the main points in regard to carbon monoxide poisoning and its relation to public hygiene, Nicloux[24] states that experimentation on man and animals gives results indicating that if the addition of carbon dioxide to oxygen has a real influence it is after all inconsiderable. He asks:

> What matters if at the end of 20 minutes, after a severe intoxication there is in the blood 20 per cent of carbon monoxide hemoglobin (treated by oxygen plus carbon dioxide) in place of 30 per cent (treated by oxygen alone), if after an hour of respiration the figures are identical or almost identical - 9 and 11 per cent? What difference if at the end of 45 minutes, after an intoxication that causes 35 to 40 per cent carbon monoxide hemoglobin, it is only by a difference of about 5 per cent in the percentage of carbon monoxide hemoglobin that gives the advantage to one method in comparison with the other? Only a few minutes more of breathing oxygen alone in order to obtain the same results!

Nicloux, in regard to treatment with air plus carbon dioxide, found that carbon dioxide added to air favored the departure of carbon monoxide better than air alone, but that the elimination always remained very inferior to that resulting from treatment with pure oxygen.

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[24] - Nicloux, M., "L'oxyde de carbone et l'hygiène": Annales d'hygiène publique, industrielle et sociale, t. 4, 1926, pp. 637-663.